Thermodynamics and Pinning of the Vortex Liquid State

Scientific Achievement

The vortex liquid state is ubiquitous to all high temperature superconductors and currently poses a large barrier to achieve the promise of high critical currents at high temperatures in these novel superconducting systems. One of the grand challenges of high temperature superconductivity is to conceive new pinning mechanisms or material modification methods which could arrest the flow of the vortex liquid and lead to the generation of high critical currents at high temperatures and magnetic fields. Unfortunately, the electric transport behavior induced by vortex liquid motion does not exhibit any notable characteristics that could provide a clue for deeper exploration. Using high-energy, heavy-ion irradiation to induce a modicum of columnar defects to probe the pinning nature of the vortex liquid, we uncovered the existence of a novel phase transition in the liquid state associated with a vortex line tension transformation.

The vortex line tension transition was measured as a function of field and temperature by monitoring the onset of anisotropic vortex pinning behavior in the liquid state due to the irradiation induced columnar defects. We obtained three remarkable results: (i) the vortex line tension transition extends to very high magnetic fields, even beyond the upper critical point, (ii) the pinning energy of the vortices in the liquid state due to columnar defects does not extrapolate to zero, but instead, saturates at high magnetic fields and (iii) the line tension transition is independent of the density and types of correlated defects.

Future studies will include (i) ultra-sensitive nano-calorimetery measurements to shed light upon the thermodynamic nature of the line tension transition and (ii) transport measurements on focused ion beam sculptured meso-crystal bridges to investigate single vortex/defect pinning in the liquid state. Furthermore, the high control of induced disorder afforded by heavy ion irradiation and the close interplay of the vortex-vortex interaction and thermal energies provide a propitious opportunity to experimentally explore one of the fundamental questions in the physics of phase transformations, the evolution of a first order transition into higher order, with unprecedented control.

Significance

Our results indicate an intrinsic phase transformation within the vortex liquid state. The vanishing of the vortex line tension in the liquid state may signal an upper limit to vortex pinning in the presence of correlated disorder and may have strong implications for technological applications of these materials. Our work provides the first step in understanding the pinning nature of the vortex liquid state and will lead to new designs and mechanisms for vortex pinning in the liquid state.

Performers

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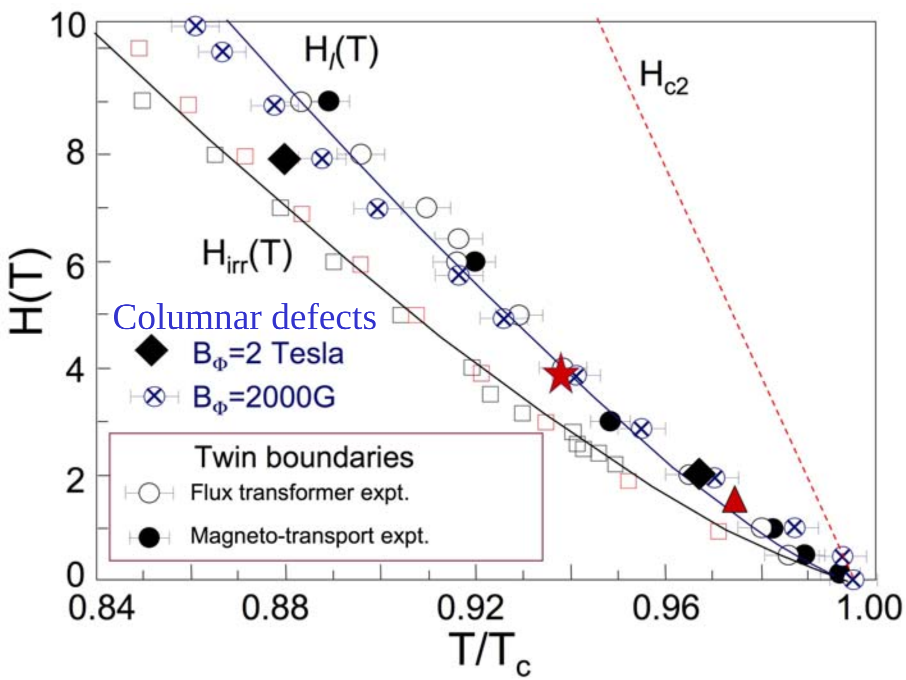
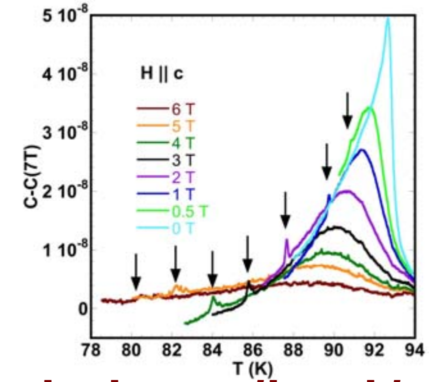
Universal vortex line tension transition in the liquid state of $YBa_2Cu_3O_7$ crystal with correlated disorder

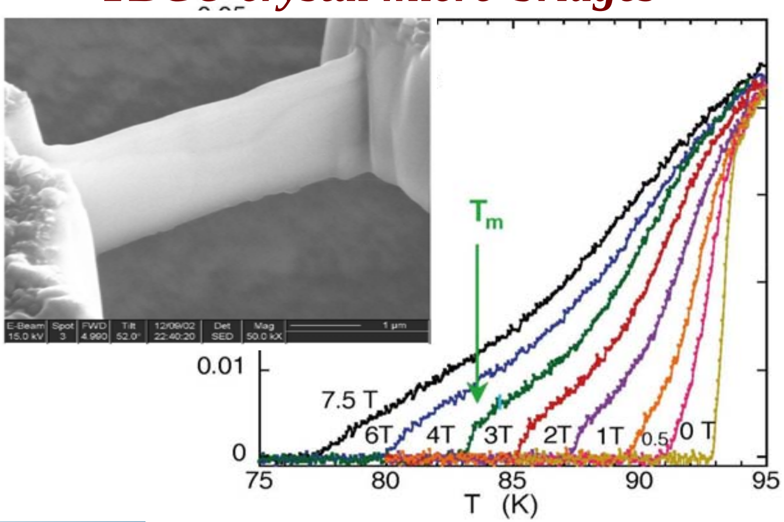


Columnar defects (◆ ⊗ ▲); Twin boundaries (● ○);
Splayed columnar defects (★)

Thermodynamics of the liquid state with nano-calorimetry



Single defect pinning studies with YBCO crystal micro-bridges



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